ONE PIECE INTERCONNECT FROM CHANNEL CHIP TO HEAD SLIDER IN A VOICE COIL ACTUATOR FOR A DISK DRIVE

Cross Reference to Related Applications

This is a divisional application of US Patent Application Number 10/101,809, filed March 19, 2002, entitled: One Piece Interconnect From Channel Chip to Head Slide.

Technical field

This invention relates to the interconnection of the read-write head in a head slider to the channel chip in a voice coil actuator used in a disk drive.

Background Art

Disk drives are an important data storage technology, which is based on several crucial components. These components include the interconnection between the read/write heads, which actually communicate with a disk surface containing the data storage medium, and the read/write interfaces of the disk drive. While there has been great progress in disk drives, there are problems, which have yet to be solved.

Figure **1A** illustrates a typical prior art high capacity disk drive **10** including actuator arm **30** with voice coil **32**, actuator axis **40**, suspension or head arms **50-58** with slider/head unit **60** placed among the disks.

Figure **1B** illustrates a typical prior art high capacity disk drive **10** with actuator **20** including actuator arm **30** with voice coil **32**, actuator axis **40**, head arms **50-56** and slider/head units **60-66** with the disks removed.

Since the 1980's, high capacity disk drives **10** have used voice coil actuators **20-66** to position their read/write heads over specific tracks. The heads are mounted on head sliders **60-66**, which float a small distance off the disk drive surface when in operation. Often there is one head per head slider for a given disk drive surface. There are usually multiple heads in a single disk drive, but for economic reasons, usually only one voice coil actuator.

Voice coil actuators are further composed of a fixed magnet actuator **20** interacting with a time varying electromagnetic field induced by voice coil **32** to provide a lever action via actuator axis **40**. The lever action acts to move head arms **50-56** positioning head slider units **60-66** over specific tracks with remarkable speed and accuracy. Actuator arms **30** are often considered to include voice coil **32**, actuator axis **40**, head arms **50-56** and head sliders **60-66**. Note that actuator arms **30** may have as few as a single head arm **50**. Note also that a single head arm **52** may connect with two head sliders **62** and **64**.

The evolution of disk drives stimulated the computer revolution. While contemporary actuator designs are essential to the progress to date, there remain problems limiting the reliability and capability of disk drives built with contemporary voice actuators. One problem has to do with the method of electrically interconnecting heads to the head interface electronics.

Figure **2** illustrates a simplified circuit diagram of a disk drive controller Printed Circuit Board (PCB) **1000**, with channel interface **1140** controlling MR read/write heads **200-206** of the prior art, using connector **226**, flex circuits **224** and **210-216**, as well as actuator PCB **220**.

Disk drive controller Printed Circuit Board (PCB) **1000** includes computer **1100** interacting with channel interface **1140**. Channel controller **1140** controls read-write preamplifier **222**, which communicates using separate read differential signal pairs (**r+** and **r-**) and write differential signal pairs (**w+** and **w-**) with the MR read/write heads **200-206**.

Note that connector **226** mechanically couples **1150** with connector **230** to electrically couple channel interface **1140** through read-write preamplifier **222** to MR read-write head **200**.

Note also that different prior art disk drives may have only one MR read-write head **200**, or more than one MR read-write heads (**202-206**).

The interconnection between MR read-write head **200**, preamplifier **222** and connection **226**, begins at head slider **60** and involves several distinct circuits which must be soldered

together to provide this interconnection. Today, the actuator PCB **220** is connected to separate flex circuits coupling to connector **226** as well as separate flex circuits **210-216**, coupling to MR read-write heads **200-206**, respectively.

Computer **1100** within embedded disk controller PCB **1000** receives readings of the spin valve voltage **V_rd** from an analog read/write interface including channel interface **1140** coupled **1152-230-1150-226-224** to read-write preamplifier **220**. Computer **1100** also controls the read current **Ir_set** for read differential signal pair **r+** and **r-**, as well as the write current **Iw_set** for write differential signal pair **w+** and **w-**.

Coupling **1152** usually involves printed circuit board traces to connector **230**. Coupling **1150** indicates the mechanical coupling of connector **230** to connector **226**. Connector **226** couples via flex circuit **224** with read-write preamplifier **222** through actuator PCB **220**.

Read-write preamplifier **220** couples through actuator PCB **220** via flex circuit **210** to MR read-write head **200**. Read-write preamplifier **220** couples through actuator PCB **220** via flex circuit **212** to MR read-write head **202**. Read-write preamplifier **220** couples through actuator PCB **220** via flex circuit **214** to MR read-write head **204**. Read-write preamplifier **220** couples through actuator PCB **220** via flex circuit **216** to MR read-write head **206**.

The process of reading the data storage surface using MR read/write head **200** includes the following. Computer **1100** accesses **1122** a memory **1120**. Memory **1120** contains program system **1128**. Memory **1120** typically includes a non-volatile memory component. This non-volatile memory component is often used to store program system **1128**.

Figures **3A**, **3B**, **3C** and **3D** illustrate a prior art actuator arm from the top view, detailed portion of top view, side view and front views, respectively.

Figure **3A** illustrates a top view of a prior art actuator arm **30** showing head arm **50**, actuator axis **40**, and head slider **60** of Figure **1** with detail region **70** illustrated in Figure **3B**.

Figure **3B** illustrates a top view of detail region **70** of Figure **3A**.

Figure **3C** illustrates a side view of part of detail region **70** of Figure **3B** indicating the interconnections **74-80** via various head sliders as found in the prior art. Each of these labeled interconnections includes two pairs of differential signals. One differential signal pair interconnects a read head to a read interface of the disk drive. The other differential signal pair interconnects a write head to a disk drive write interface.

Figure **3D** illustrates a different perspective on Figure **3C**, illustrating that these signal interconnections **74** may be embodied as various forms of cables attached to a head arm, including flex and ribbon cables.

Figure **3E** illustrates an alternative prior art electrical interconnection scheme for **74-80** traversing along head arm **50**, essentially parallel to head arm **50**.

Figure **3E** is typical of prior art uses of flex circuitry to interconnect head sliders and disk read/write interfaces. Four individual traces are used for the read differential signal pair (**R+**, **R-**) and the write differential signal pair (**W+**, **W-**).

The prior art teaches interconnecting multiple pieces of interconnection circuitry **224**, **220**, and **210** between the read-write head **200** in the head slider **60** and channel interface **1140** coupling **226**. Assembling these interconnection circuits with these multiple flex circuits usually includes reflow bonding and/or ultra-sonic bonding of these flex circuits.

Figure **4** illustrates a prior art method **1500** of making the interconnection circuit from a read-write head **200** to embedded disk controller PCB connector **226**.

Arrow **1510** directs the flow of execution from starting operation **1500** to operation **1512**. Operation **1512** performs bonding read-write head **200** to flex circuit **210**. Arrow **1514** directs execution from operation **1512** to operation **1516**. Operation **1516** terminates the operations of this flowchart.

Arrow **1520** directs the flow of execution from starting operation **1500** to operation **1522**. Operation **1522** performs bonding flex circuit **210** to actuator PCB **220**. Arrow **1524**

directs execution from operation **1522** to operation **1516**. Operation **1516** terminates the operations of this flowchart.

Arrow **1530** directs the flow of execution from starting operation **1500** to operation **1532**. Operation **1532** performs bonding electronic components including at least read-write preamplifier **222** to actuator PCB **220**. Arrow **1534** directs execution from operation **1532** to operation **1516**. Operation **1516** terminates the operations of this flowchart.

Arrow **1540** directs the flow of execution from starting operation **1500** to operation **1542**. Operation **1542** performs bonding flex circuit **224** to actuator PCB **220**. Arrow **1544** directs execution from operation **1542** to operation **1516**. Operation **1516** terminates the operations of this flowchart.

Arrow **1550** directs the flow of execution from starting operation **1500** to operation **1552**. Operation **1552** performs bonding flex circuit **224** to connector **226**. Arrow **1554** directs execution from operation **1552** to operation **1516**. Operation **1516** terminates the operations of this flowchart.

The prior art teaches several interconnection circuit variations, including three interconnection circuits as discussed above, as well as some examples of two interconnection circuits. The three interconnection circuit scheme contents are referred to as main flex (actuator PCB **220**), bridge flex circuit (**224**) and suspension flexure (**210-216**). The two interconnection circuits are found in two variations. The first variation contains a main flex circuit (**224** plus **220**) and suspension flexure (**210-216**). The second variation contains a main flex circuit (**220**) and a combined bridge flex circuit with suspension flexure (**224** plus **210-216**).

In any of the prior art approaches, multiple interconnection circuits are typically bonded together to create electrical couplings using either an ultrasonic bonding process or a reflow bonding process to create the interconnection circuit between connector **226**, read-write preamplifier **222**, and one or more MR read-write heads **200-206**.

While this method of interconnection has achieved widespread production use in the manufacture of disk drives, it has some problems due to the employed bonding process.

Reflow bonding processes apply heat to a solder paste or solid to form a solder joint. The paste or solid is melted, and then allowed to cool to create the solder joint. Ultrasonic bonding processes use ultrasonic energy to form a solder joint at essentially room temperature. Each of these bonds increases parasitic capacitance as well as increases parasitic inductance on the bonded line. Each bonding step increases the manufacturing cost for the interconnection circuit, and consequently, for the voice coil actuators and, ultimately, for the disk drives containing these interconnection circuits.

What is needed is an interconnection circuit minimizing the number of wire bonds on each line. What is further needed is a method of making the interconnection circuit which minimizes the number of bonding steps required to make the interconnections between MR read-write heads, preamplifier and connector.

Summary of the invention

The invention solves at least all the needs discussed in the prior art. The invention includes an interconnection circuit minimizing the number of wire bonds on each line. The invention further includes a method of making the interconnection circuit minimizing the number of bonding steps required to make the interconnections between the MR read-write heads, the preamplifier and the connector.

A single flex interconnection circuit **2000** bonds to connector **226**, electronic components including at least preamplifier **222** and at least one MR read-write head **200** (see Figure **5**). Flex interconnection circuit **2000** provides the least number of bonds for each of the lines involved. The invention includes the flex interconnection substrate with bonding sites for connector **226**, electronic components and MR read-write heads.

The method **3000** (see Figure **6A**) of making flex interconnection circuits **2000** involves the least number of bonding steps necessary to provide interconnection between connector **226**, electronic components including preamplifier **222** and at least one MR read-write head **200**. The bonded electronic components may include one or more resistors as well as one or more capacitors. Note that more than one MR read-write head

(200-206) may be bonded to flex interconnection circuit **2000** in one operation **3032** of Figure **6A**.

Alternatively, a method **3300** (Figure **7**) coupling connector **226**, preamplifier **222** and several MR read-write heads **(200-206)** may apply the method **3000** of Figure **6A** to interconnect the first MR read-write head **200** and then successively bond other MR read-write heads in operations **3322**, **3332**, and **3342** of Figure **7**.

The invention includes a method **3500** (Figure **8**) of assembling an actuator using flex interconnection circuit **2000**. The invention further includes actuators as the product of the process making them from flex interconnection circuits **2000**. The invention includes disk drives made from the process of assembling the inventive actuators into the disk drives.

Both the actuators and disk drives show improved reliability and noise suppression characteristics from minimized number of bonds per line in flex interconnection circuit **2000**. Both the actuators and disk drives cost less to manufacture, because of the reduced manufacturing cost of flex interconnection circuit **2000**.

These and other advantages of the present invention will become apparent upon reading the following detailed descriptions and studying the various figures of the drawings.

Brief Description of the Drawings

Figure **1A** illustrates a typical prior art high capacity disk drive **10** including actuator arm **30** with voice coil **32**, actuator axis **40**, suspension or head arms **50-58** with slider/head unit **60** placed among the disks;

Figure **1B** illustrates a typical prior art high capacity disk drive **10** with actuator **20** including actuator arm **30** with voice coil **32**, actuator axis **40**, head arms **50-56** and slider/head units **60-66** with the disks removed;

Figure **2** illustrates a simplified circuit diagram of a disk drive controller Printed Circuit Board (PCB) **1000**, with channel interface **1140** controlling MR read/write heads **200-206**

of the prior art, using connector **226**, flex circuits **224** and **210-216**, as well as actuator PCB **220**;

Figure **3A** illustrates a top view of a prior art actuator arm **30** showing head arm **50**, actuator axis **40**, and head slider **60** of Figure **1** with detail region **70** illustrated in Figure **3B**;

Figure **3B** illustrates a top view of detail region **70** of Figure **3A**;

Figure **3C** illustrates a side view of part of detail region **70** of Figure **3B** indicating the interconnections **74-80** via various head sliders as found in the prior art;

Figure **3D** illustrates a different perspective on Figure **3C**, illustrating that these signal interconnections **74** may be embodied as various forms of cables attached to a head arm, including flex and ribbon cables;

Figure **3E** illustrates an alternative prior art electrical interconnection scheme for **74-80** essentially parallel to head arm **50**;

Figure **4** illustrates a prior art method **1500** of making the interconnection circuit from a read-write head **200** to embedded disk controller PCB connector **226**;

Figure **5** illustrates a single flex interconnect circuit **2000** providing interconnection between connector **226** via preamplifier **222** and MR read-write head **200**;

Figure **6A** illustrates a method **3000** for making flex interconnection circuit **2000**, coupling connector **226** through preamplifier **222** with MR read-write head **200**;

Figure **6B** illustrates a detail flowchart of operation **3022** of Figure **6A** for bonding electronic components to flex interconnection circuit **2000**;

Figure **7** illustrates a method **3300** for making an interconnection circuit, coupling connector **226** through preamplifier **222** with at least two MR read-write heads using the method **3000** of Figure **6A**; and

Figure **8** illustrates a method **3500** for assembling a voice coil actuator using an interconnection circuit as the product of the method **3000**.

Detailed Description of the Invention

The invention includes an interconnection circuit minimizing the number of wire bonds on each line. The invention further includes a method of making the interconnection circuit minimizing the number of bonding steps required to make the interconnections between MR read-write heads, preamplifier and connector.

Figure **5** illustrates a single flex interconnect circuit **2000** providing interconnection between connector **226** via preamplifier **222** and MR read-write head **200**.

Note that Figure **5** also illustrates a an alternative schematic view of flex interconnection substrate **2000** with bonding sites for connector **226**, preamplifier **222** and MR read-write head **200**.

A single flex interconnection circuit **2000** bonds to connector **226**, electronic components including at least preamplifier **222** and at least one MR read-write head **200**. Flex interconnection circuit **2000** provides the least number of bonds for each of the lines involved.

The invention includes the flex interconnection substrate with bonding sites for connector **226**, electronic components and MR read-write heads. The electronics components include at least a preamplifier **222**.

The electronics component collection may further include at least one capacitor. The electronics component collection may also further include at least one resistor.

Flex interconnection circuit **2000** includes a flex interconnection substrate with the following bonding to the substrate: connector **226**, an electronics component collection including at least preamplifier **222** and at least one MR read-write head. The bonding of each of these is done at a specific bonding site. As will be apparent to one of skill in the art, when multiple MR read-write heads are being bonded, there are separate, though similar, bonding sites for each of the MR read-write heads.

Figure **3F** illustrates a schematic view of a preferred bonding site for connector **226**. Figure **3G** illustrates a schematic view of a preferred bonding site for an electronic components collection including preamplifier **222**, two capacitors **C1** and **C2**, as well as, resistor **R1**. Figure **3H** illustrates a schematic view of a preferred bonding site for MR read-write head **200**.

The flex interconnection circuit **2000** couples connector **226** with preamplifier **222** through the bonding of connector **226** and preamplifier **222** to the flex interconnection substrate.

It is preferred that preamplifier **222** support a coupled communication via connector **226** based upon the following pin-out from reading Figure **3F** bonding site for connector **226** from left to right, top row of pins on the

VC+	VC-
GND	GND
GND	VSS(-5V)
FLT/DBHY/TEMP	VDD(+5V)
GND	WDY
MRB/FAST	WDX
SCLK	SDATA
R/W	SDEN
No Connect	RDY
WSRV/ABHV	RDX

Table One illustrates a preferred pinout for connector **226** providing a coupling to preamplifier **222**.

Preamplifier **222** may preferably be the 81G5014 integrated circuit manufactured by Marvell Semiconductor. The capacitance of **C1** and **C2** may preferably be 0.01 micro-Farads to within acceptable tolerances. The resistance of **R1** may preferably be 12.4K Ohms to within acceptable tolerances. Each of these electronics component collection members is preferably packaged in a surface mount compatible package.

The flex interconnection circuit **2000** couples preamplifier **222** with MR read-write head **200** through the bonding of preamplifier **222** and MR read-write head **200** to the flex interconnection substrate. Figure **3H** illustrates a preferred bonding site for MR read-write head **200**.

Figure **3I** illustrates a preferred cross section view of the read differential signal pair **r-** and **r+** and the write differential signal pair **w+** and **w-** of the flex interconnection substrate coupling a MR read-write head bonding site with the preamplifier bonding site.

The preferred base thickness beneath these signal pairs is from 15 to 25 micrometers, with a preferred overlay above the signal pairs from 5 to 33 micrometers. The preferred read trace width is from 100 to 125 micrometers, with preferred spacing between the read differential signals from 40 to 75 micrometers. The preferred spacing between the read and write differential signal pairs is from 100 to 170 micrometers. The preferred write signal width is from 100 to 125 micrometers. The preferred spacing between write differential signals is from 40 to 75 micrometers.

While the read and write differential signal traces may be made from several metals including copper, aluminum, silver and gold, the preferred composition is copper, with a gold trace at the bonding sites of the MR read-write heads.

Figure **6A** illustrates a method **3000** for making flex interconnection circuit **2000**, coupling connector **226** through preamplifier **222** with MR read-write head **200**.

Arrow **3010** directs the flow of execution from starting operation **3000** to operation **3012**. Operation **3012** performs bonding connector **226** to flex interconnection circuit **2000**. Arrow **3014** directs execution from operation **3012** to operation **3016**. Operation **3016** terminates the operations of this flowchart.

Arrow **3020** directs the flow of execution from starting operation **3000** to operation **3022**. Operation **3022** performs bonding electronic components including at least read-write preamplifier **222** to flex interconnection circuit **2000**. Arrow **3024** directs execution from operation **3022** to operation **3016**. Operation **3016** terminates the operations of this flowchart.

Arrow **3030** directs the flow of execution from starting operation **3000** to operation **3032**. Operation **3032** performs bonding at least one MR read-write head to flex interconnection circuit **2000**. Arrow **3034** directs execution from operation **3032** to operation **3016**. Operation **3016** terminates the operations of this flowchart.

As will be apparent to one of skill in the art, when more than one MR read-write head is involved, it is often preferable to bond them all concurrently to the flex interconnection substrate through operation **3032**.

Figure **6B** illustrates a detail flowchart of operation **3022** of Figure **6A** for bonding electronic components to flex interconnection circuit **2000**.

Arrow **3060** directs the flow of execution from starting operation **3022** to operation **3062**. Operation **3062** performs bonding read-write preamplifier **222** to flex interconnection circuit **2000**. Arrow **3064** directs execution from operation **3062** to operation **3066**. Operation **3066** terminates the operations of this flowchart.

Bonding electronic components to flex interconnect circuit **2000** may further include at least one of the following operations of Figure **6B**.

Arrow **3070** directs the flow of execution from starting operation **3022** to operation **3072**. Operation **3072** performs bonding at least one resistor to flex interconnection circuit **2000**. Arrow **3074** directs execution from operation **3072** to operation **3066**. Operation **3066** terminates the operations of this flowchart.

Arrow **3080** directs the flow of execution from starting operation **3022** to operation **3082**. Operation **3082** performs bonding at least one capacitor to flex interconnection circuit

2000. Arrow **3084** directs execution from operation **3082** to operation **3066**. Operation **3066** terminates the operations of this flowchart.

Figure **7** illustrates a method **3300** for making an interconnection circuit, coupling connector **226** through preamplifier **222** with at least two MR read-write heads using the method **3000** of Figure **6A**.

Arrow **3310** directs the flow of execution from starting operation **3300** to operation **3312**. Operation **3312** performs applying the method **3000** to make the flex interconnection circuit coupling connector **226** through preamplifier **222** to first MR read-write head **200**. Arrow **3314** directs execution from operation **3312** to operation **3316**. Operation **3316** terminates the operations of this flowchart.

Arrow **3320** directs the flow of execution from starting operation **3300** to operation **3322**. Operation **3322** performs bonding a second MR read-write head **202** to the flex interconnection circuit **2000** to provide the coupling of connector **226** through preamplifier **222** to the second MR read-write head **202**. Arrow **3324** directs execution from operation **3322** to operation **3316**. Operation **3316** terminates the operations of this flowchart.

The method **3300** may further include the following operations of Figure **7**.

Arrow **3330** directs the flow of execution from starting operation **3300** to operation **3332**. Operation **3332** performs bonding a third MR read-write head **204** to the flex interconnection circuit **2000** to provide the coupling of connector **226** through preamplifier **222** to the third MR read-write head **204**. Arrow **3334** directs execution from operation **3332** to operation **3316**. Operation **3316** terminates the operations of this flowchart.

Arrow **3340** directs the flow of execution from starting operation **3300** to operation **3342**. Operation **3342** performs bonding a fourth MR read-write head **206** to the flex interconnection circuit **2000** to provide the coupling of connector **226** through preamplifier **222** to the fourth MR read-write head **206**. Arrow **3344** directs execution

from operation **3342** to operation **3316**. Operation **3316** terminates the operations of this flowchart.

Figure **8** illustrates a method **3500** for assembling a voice coil actuator using the product of the method **3000**.

Arrow **3510** directs the flow of execution from starting operation **3500** to operation **3512**. Operation **3512** performs affixing to a head slider **60** a MR read-write head **200** bonded to the flex interconnection circuit **2000** made with the method **3000** to create a head arm **50** in an actuator **30**. Arrow **3514** directs execution from operation **3512** to operation **3516**. Operation **3516** terminates the operations of this flowchart.

Arrow **3520** directs the flow of execution from starting operation **3500** to operation **3522**. Operation **3522** performs anchoring the flex interconnection circuit **2000** about the preamplifier **222** to the actuator **30**. Arrow **3524** directs execution from operation **3522** to operation **3516**. Operation **3516** terminates the operations of this flowchart.

Arrow **3530** directs the flow of execution from starting operation **3500** to operation **3532**. Operation **3532** performs binding the flex interconnection circuit **2000** to the head arm **50** between the preamplifier **222** and the MR read-write head **200**. Arrow **3534** directs execution from operation **3532** to operation **3516**. Operation **3516** terminates the operations of this flowchart.

The preceding embodiments have been provided by way of example and are not meant to constrain the scope of the following claims.